Design Of Readout System for an Resistive Plate Chamber

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Abstract

This paper aims at discussing the design of a readout system for a Resistive Plate Chamber. It discusses the selection of a readout system and the solution to the problem of signal transmission. It is also discusses the experimental procedure involved in design of the readout system and the analysis of data collected from the experiment.

Contents:

Introduction

I. Global View

The standard model proposed by particle physicists says there are twelve fundamental particles that make up matter. The fundamental particles are six quarks and six leptons. There are three charged leptons and three uncharged leptons. The charged leptons are electron, tau and muon. Each of these charged leptons has an uncharged neutral leptons associated with it. These neutral leptons are called neutrinos, thus we have electron neutrino V_e, muon neutrino V_u and tau neutrino V_t. These three types are considered as the three flavors of the neutrino.

Within the standard model, the neutrino has a zero mass, a zero charge and a half spin. Neutrinos interact only through the weak nuclear force. Most neutrinos rarely interact so they pass through the earth and objects undisturbed, i.e. they retain their structures after going through obstacles. They are only detected by huge tons of detector built to detect them. The major source of neutrinos is the Sun. The sun produces electron neutrinos as a by-product of nuclear fusion.

$$p+p+p+p \longrightarrow {}^{4}_{2}He + 2e^{-} + 2\nu_e \qquad \text{Eq 1}$$

In recent experiments to detect electron neutrinos from the sun, it appears too few neutrinos are detected compared to the amount known to be given out by the sun. For instance a light water Cherenkov experiment at Kamioka, Japan, upgraded to detect solar neutrinos in 1986, found one half of the expected events for the part of the neutrinos spectrum, which they are sensitive to. Other similar experiments, like the Sudbury Neutrino Observatory Experiment, to detect these electron neutrinos have not been able to account for all the neutrinos produced by the Sun.

The detectors used in the experiments could only detect solar neutrinos, which are electron neutrinos. A theory was proposed that some of the electron neutrinos might change their flavors to the sister neutrinos' while traveling down the earth, before they are detected. If this hypothesis is true, it will be proof of the speculation of neutrinos being massive.

At Fermilab, Fermi National Accelerator Laboratory, a new experiment, called the Main Injector Neutrino Oscillation Search (MINOS) has been initiated to study the effect of the oscillations of neutrinos. The MINOS experiment is a long-baseline experiment that will produce a beam of mainly moun neutrinos. The fact that the experiment is long-baseline gives the moun neutrinos that will be produced at the lab more time and chance to change flavor before they reach the detecting facility. It will also allow the experimenters more chances to detect their masses if they have any, than in a short – baseline experiment.

The experiment will use facilities built by the Neutrinos at the Main Injector (NuMI) Project at the Laboratory. The new Main Injector that was completed in 1999 has the capacity to produce intense neutrino beams required for such a long – baseline experiment. Neutrinos are produced from the Fermilab main injector by smashing high energy protons into a carbon target, producing kaons and pions, which are unstable in nature. The kaons and pions will in turn decay into neutrinos.

The muon neutrino beams are then sent 735 kilometers to a far detector in the Soudan Mine in Minnesota. Before the neutrino beam leaves the Fermilab site for the far mine detector, another detector at Fermilab will characterize it just after it is produced. This detector known as the near detector is going to be built as a small replica of the far detector. The two detectors are capable of detecting the characteristics of the three types of neutrinos. A difference between characteristics of the neutrino's interactions in these two detectors would provide evidence of neutrino oscillation. The near detector will be built at Fermilab starting in 2003, and the far detector is about half completed. The neutrino beam will start running in late 2004.

The next phase of the MINOS experiment will be to build a detector to look for the appearance of electron neutrinos. This detector will be built on the surface (not in a mine), but also in Minnesota. The type of detector that will be built is not yet known. A group at Fermilab has formed a research project called "Loden"(Low Density), to study the feasibility of building such a detector from a glass apparatus called Resistive Plate Chambers (RPCs) to detect the particles produced in the Neutrino Interactions. The Loden group will also study the effect of cosmic rays flux on the detector, whether it will cause too high a rate of background effect or fake electron neutrino signals.

II. My Project

As a summer intern in the Loden group, I participated in the following activities:

1) Building of a readout system for RPCs
2) Developing method of connecting the readout system to the electronic system
3) Writing software to collect data
4) Analyzing of collected data.

This paper will focus on the design of a readout system for a Resistive Plate Chamber.

Theory, Design and Implementation of a Readout System

I. A Resistive Plate Chamber Detector

An RPC plate is a glass chamber filled with a mixture of gases. It is used to detect the presence of particles through their interaction with the molecules of gases. The RPC is connected to a high voltage source to provide electric field for electron drift. Particles entering the RPC will strip electrons from the gas molecules, which results in free electrons. These electrons will be accelerated by the electric field and as a result they will liberate more electrons. Enough gas molecules are eventually ionized to allow the liberated electrons to form a spark. The spark formed induces a voltage in an adjoining readout system. This voltage is then send as signals to an electronic end for analysis. Twenty RPCs were brought in from Virginia Tech, without readout systems. The responsibility fell on the group to design a readout system for the RPCs.

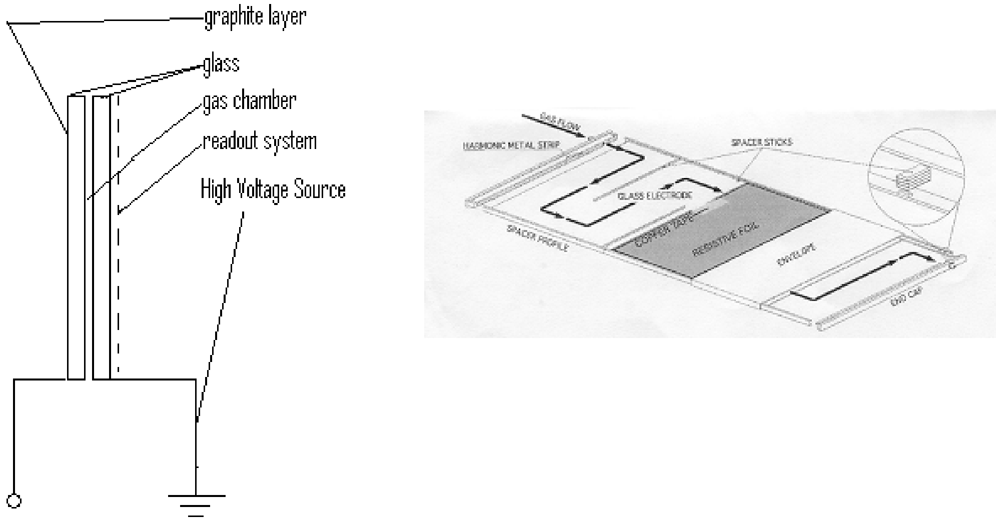

Fig 1. Schematic and layout of an RPC plate

II. Design and Implementation of a Readout System

In designing the read out system the following factors were put into consideration.

1) Cost
2) Efficiency
3) Availability
4) Construction.

The readout plate or board must be able to detect the induced signals from the RPC plate without significant loss or alteration of signal. Since the signal had to be picked up by induction, the readout system that was considered was the inductive readout system as opposed to other forms such as picture readout. The ideal inductive readout system is a board with two different surfaces, one for signal transmission and the other side for signal protection. It is basically a capacitor like setup; with two plates separated by a dielectric material.

Two methods of constructing the readout board were considered, the padded readout system and the strip readout system. In the padded readout system, the readout board is partitioned into squares and each square is attached to a signal cable. Each square is configured to pickup the signal that occurs in the RPC area adjoining it. A square pad will pick up an induced voltage on the board and it will then send pulses to an electronics end. The square pad that gets induced gives the relative location at which the particle interaction occurred in the RPC. The other method is the strip method, where strips are made on a board. Two readout boards are used, one is stripped horizontally and the other is stripped vertically relative to the position of the RPC plate. An induced voltage by the RPC plate will be picked by one of the horizontal and vertical strips. The vertical strip and horizontal strip that picks up the voltage will give the coordinate of the region in which the spark or event occurred in the RPC.

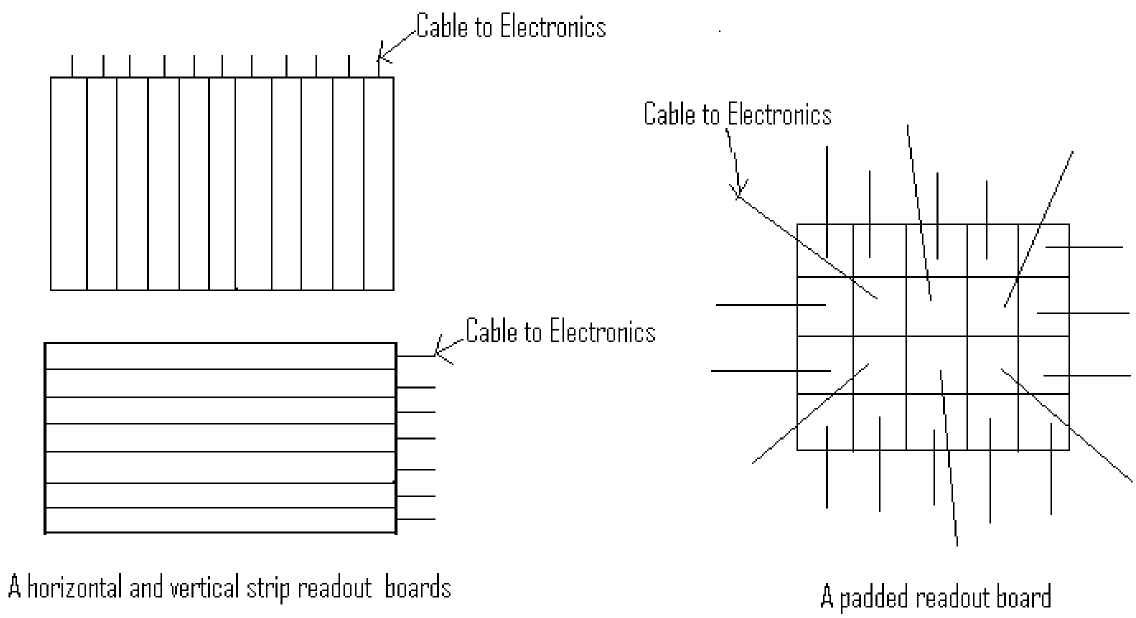

Fig. 2: Diagrams of a padded and strip readout system.

The strips method was chosen over the padded method due to the following reasons.

1) It is easier to make strips on a board than to make square segments.
2) For a large area of RPC, the signal cables from the square pads will require a large number of connecting modules at the electronics crate compare to a signals form strips.

After the strips method was chosen, the material for construction had to be selected. The usual way of constructing the strip readout is with a material called mylar and copper. Strips of copper are carefully laid on a thin board made of mylar and on the other side of the board a wave-guide is attached to prevent lost of signals in the copper over a long distance. The problem with using mylar and copper in constructing a strip readout board is the cost and construction. Mylar is a very costly material. It is also very difficult to construct and place the copper on the mylar board. It did not meet the criteria listed for the project.

An alternative to the mylar board was suggested by Dr. Adam Para, leader of the Loden group. According to Dr. Para, a recent experiment at Virginia Technological University used a home insulating board, obtainable at Home-Depot, for the readout system. Following Dr Para's suggestion the board was obtained as a substitute for mylar. The insulating board obtained has two sides; one with a surface made of aluminum and the other surface is made of aluminum coated with an insulating material. The dielectric material between the two surfaces is foam. The aluminum surface will be striped while the coated surface will act as the ground, serving as signal guide.

III. Signal Transmission and Impedance Matching

A factor that needed to be addressed before experimenting was signal transmission between two cables of different impedances and between a signal cable and readout board.

Coaxial Cables.

In nuclear physics experiments, the standard transmission line for readout electronics is the coaxial cable. It is made of two concentric conductors separated by a dielectric material. The dielectric is usually made up of polyethylene or teflon. The outer cylindrical conductor is made in wire braids, it serves as ground return and it shields the central conductor from stray electromagnetic field. A plastic covering protects the entire setup.

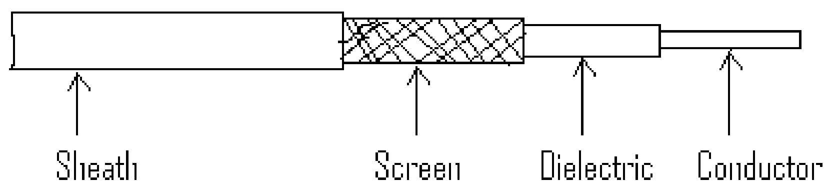

Fig 3

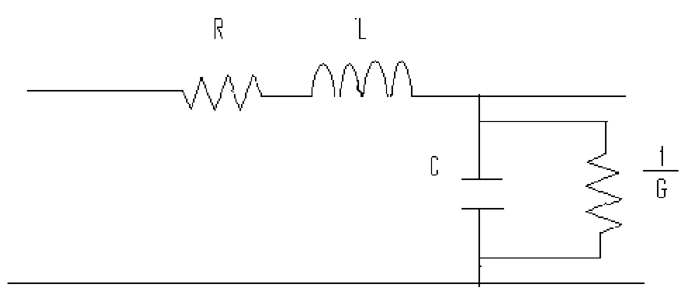

Fig. 4: Circuit layout of a coaxial cable

$$\frac{\partial^2 V}{\partial z^2} = LC\frac{\partial^2 V}{\partial^2 t} + (LG+RC)\frac{\partial V}{\partial t} + RGV \qquad \text{Eq 2}$$

Fig 4 shows the circuit diagram for a coaxial cable and equation 2 is the general equation for a coaxial cable.

Characteristics impedance of coaxial cable.

Impedance is one of the inherent and significant properties of a signal cable; it is defined as the ratio of the voltage to current in the cable.

$Zo=V/I$ Eq 3

For a coaxial cable

$$Z_o = \sqrt{\frac{L}{C}} = 60\sqrt{\frac{K_m}{K_e}}\ln\frac{b}{a}\text{ ohms} \qquad \text{Eq 4}$$

where a and b are the radii of the inner and outer conductors respectively. K_e and K_m are the relative permeability and permittivity of the dielectric material.

Reflections.

A signal in a cable is usually the sum of the original signal and a reflected signal traveling in the opposite direction. If the reflection of the signal should lap with the original, it will cause distortion of the signal. Also echoes of the original signal going back and forth can lead to spurious counts. Reflections occur when signals travel through two cables of different impedances. They occur at the boundary interface of the two cables.

If two cables of impedances R and Z are connected to each other, the value of the ratio of their difference to their sum gives the absolute value ρ of the reflection coefficient for both cables.

$$\rho = \frac{R - Z}{R + Z} \qquad \text{Eq 5}$$

When the two cables have equal impedances, then R equals Z, ρ becomes zero and reflection is avoided.

Cable Termination and Impedance matching.

Signal reflection and distortion can be avoided between cables by matching their impedances to each other. The NIM[1] standard requires that all input and output device impedances and cables impedances be 50 ohms. But there are times when two cables or devices of two different impedances need to be interconnected to each other. When this need arises, the principle of termination is used. Termination is the addition of supplementary impedance(s) to the impedances of two devices or cables to adjust the load seen by both of them at their interface. Termination can be done either in series or in parallel or a combination of both.

Experimental Procedures

I. Insight

Strips of varying widths were made on the signal plane of the board by a table saw. The ends of the ground plane of the board were cleaned with ethyl alcohol to make it conductive. These cleaned ends served as a connection part for the ground signals. Before the experiment could be continued, a problem of impedances matching in cables had to be addressed. A pulser was required to generate pulses on the board in order to monitor signal transmission.

[1] NIM is an acronym for Nuclear Instrument Module, a standard for manufacturing electronics apparatus used in high energy physics.

II. Application of Impedance Matching.

Output of pulsers are designed for 50 ohms coaxial cables and the cables that were intended to be used for pulsing the board are 120 ohms twist and flat cables. A 120 ohms cable had to be connected to a 50 ohms cable with adequate terminating impedances. If the two cables are not matched to each other appropriately, the signals coming from the pulser to the board will be distorted and the return signals coming from the board to the pulser will also be distorted. So the signals coming from the 50 ohms cable had to be matched to the 120 ohms cable, likewise for the reflected signals coming from the 120 ohms cable to 50 ohms cable. From equation 5, the absolute value of the reflection coefficient for both the original and reflected signals at the boundary of the two cables is 0.412.

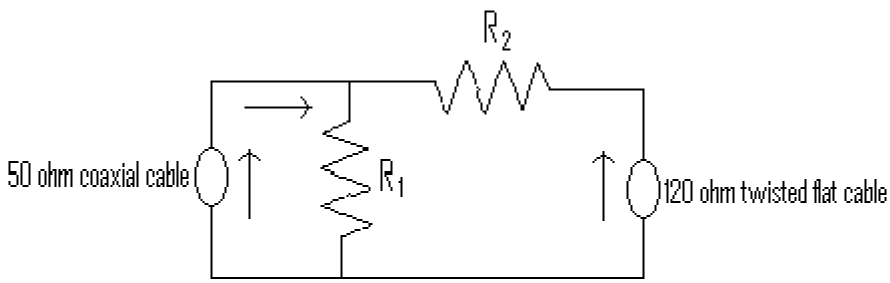

Fig 5

The above circuit was designed to terminate the two cables. It consists of two external resistances R_1 and R_2 in series and parallel combinations with the two cables. From this configuration the 120 ohms cable sees a 120 ohms signal instead of 50 ohms signal. Likewise the 50 ohms cable sees a 50 ohms signal as opposed to 120 ohms signal coming from the 120 ohms cable. The circuit also reduces the coefficient of reflection from both sides of the interface of the cable to near zero.
From the above diagram we assume two equations.

$$R_1 || (R_2 + 120) = 50$$

$$R_2 + (R_1 || 50) = 120$$

Eq 6

Solving the two equations simultaneously, we have R_1=65.46 ohms and R_2= 91.66 ohms. Using the result from above calculation, the above circuit was installed between a female bunch connector of a 120 ohms cable and a 50 ohms coaxial cable.

III. Experimental Setup

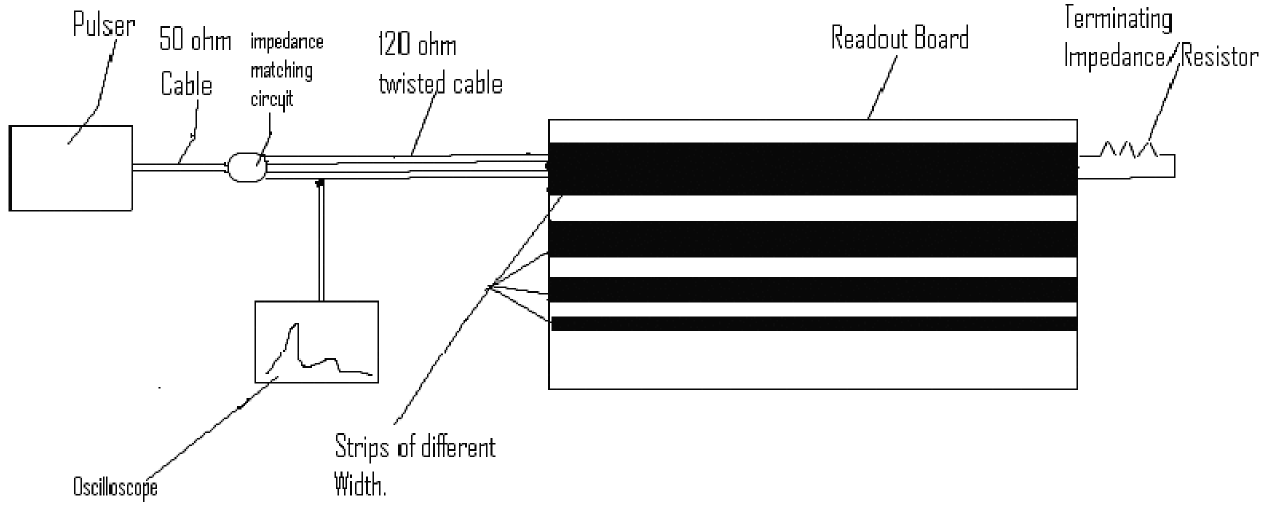

Fig 6. Setup for Experiment

The experiment was setup as shown in fig 6;the pulser sends a pulse through a 50 ohms cable and it gets into the terminating circuit where it passes on to a 120 ohms cable without been distorted. The 120 ohms cable is about 30 feet long and it is branched to an oscilloscope for study at about 5 feet from the impedance matching circuit. The end of the 120 ohms cable is connected to the readout board.

Three things were to be determined from this experimental setup.

1) The width of the strip that will give the least backend reflection
2) The terminating impedance at the back of the board for each strip
3) The strip that gives the least front end reflection, after termination .

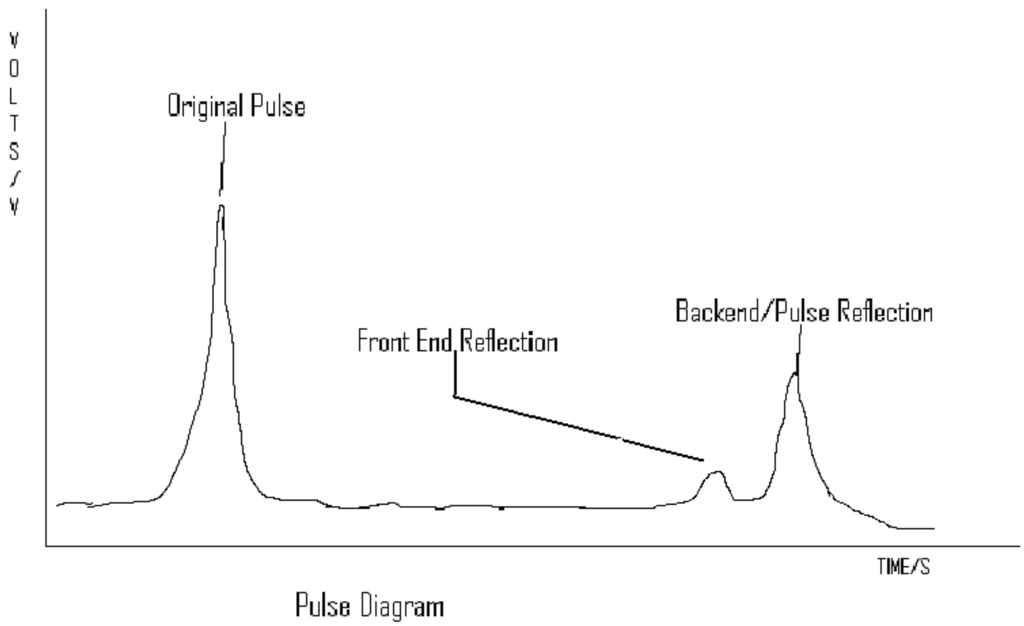

Fig 7. Signal diagram

Fig 7 shows a sketch of a typical result without the terminating end impedance. For each strip, a pulse was sent, the pulse encountered a front-end reflection at the front of the board and it also encountered a back end reflection at the back. The chances of the backend reflection interfering with the original signal is high and needs to be eliminated. To get rid of the backend reflection, a terminating resistor of a value equal to impedance of the strip had to be connected to the backend. Terminating the backend with the right resistance was done on a trial and error basis. Resistors of different value were attached in turn to the back of the strip, until the one that terminated/flattened out the back end reflection on the oscilloscope display was found. The value of the terminating resistor and the oscilloscope display were recorded for further analysis. This procedure was carried out for every strip.

IV. Results

Dimension of board: length 2m,width 0.9m,thickness1.25m
Pulsar properties: Lecroy pulser supplying 2ns pulse

Strip width (cm)	Strip Width/thick -ness ratio	Terminating Impedance (Ω)
3.0	2.40	61.6
2.4	1.92	93.6
1.8	1.44	107.5
1.3	1.04	108.5
0.8	0.64	132.0
0.4	0.32	156.2

The table above shows the width of each strip tested and the terminating impedance at the backend. It also shows the width to thickness ratio of each strip.

V. Analysis of Results.

Before the results could be accepted they were tested for experimental accuracy by comparing them with a theoretical equation. The theoretical equation gives impedance as function of width to thickness ratio. To make this comparison, the impedance versus width to thickness ratio of each strip and the theoretical equation were plotted on the same graph.

The theoretical equation is stated below.

$$\left(\begin{array}{l} ER = \left(\dfrac{E_r + 1}{2} + \dfrac{E_r - 1}{2\sqrt{1 + \dfrac{10}{x}}} \right) \\ \text{for } x \le 1: \\ Zc = \dfrac{60 \ln\left(\dfrac{8}{x} + \dfrac{x}{4} \right)}{\sqrt{ER}} \\ \text{for } x \ge 1: \\ Zc = \dfrac{377}{\left(x + 1.393 + 0.667 \ln(x + 1.444) \right) \sqrt{ER}} \end{array}\right) \qquad \text{Eq 7}$$

where x = (width of strip) / (distance between strip and ground) , E_r=relative permitivity(1.05) of the dielectric between the surfaces of the board and Zc = impedance.

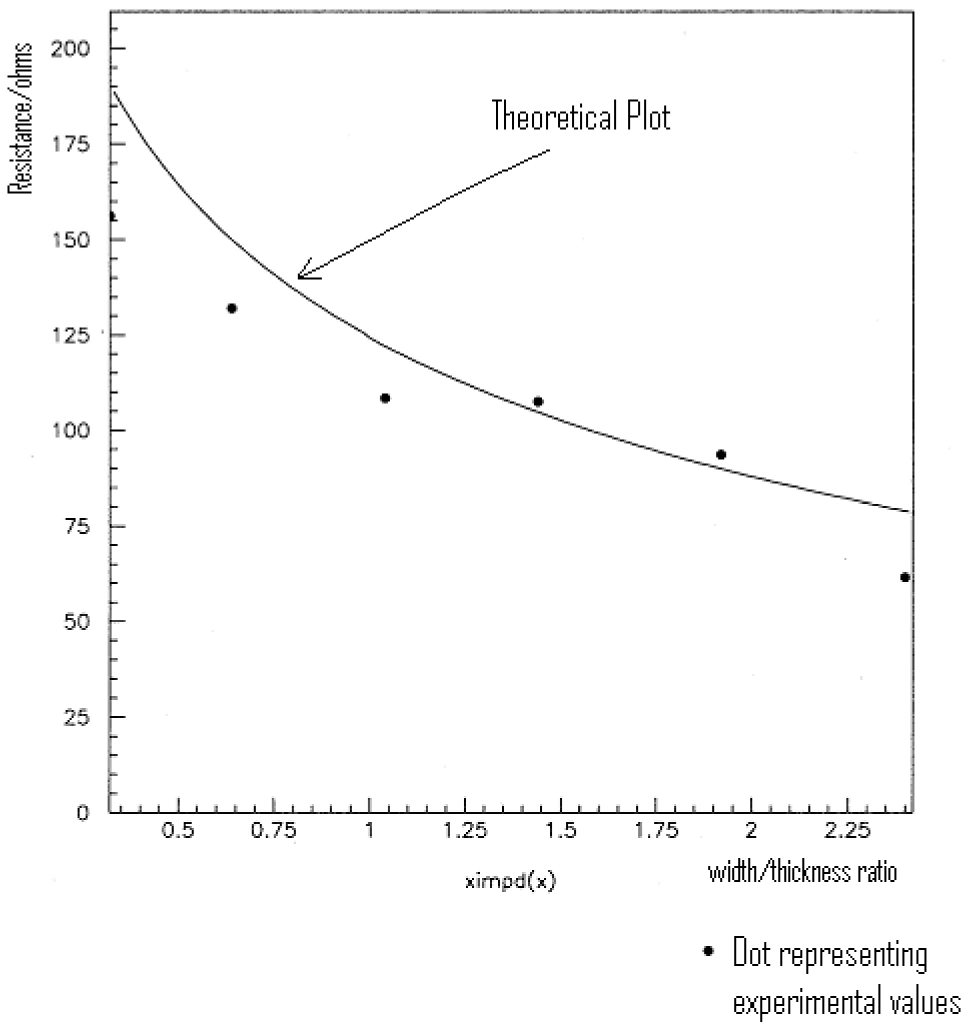

Fig. 8

As seen from fig 8. the experimental values obtained were well distributed around the predicted equation line. One could conclude that the values obtained from the experiment, were accurate to a degree permitted within the limits of experimental errors. After confirming the accuracy of the result, the next task was to select the best strip width. This was done by analysis the digital values obtained from the oscilloscope using the paw[2] software.

Selection of strip with best width

The digital value of the oscilloscope traces obtained from each strip measurement obtained was plotted on paw (see appendix). The following conclusions were made from the study and analysis of the traces.

1) All strips widths are okay for further experimental purposes
2) Strip of width 1.8 cm gave the least front-end reflection

[2] PAW is acronym for Physicists Analysis Workstation, software used for analysis of data by physicist.

3) Strip of width 1.3cm gave the 2nd least front-end reflection
4) Strip of width 3cm was selected for further experimental purposes
5) Reflections at the front end are negligible.

Conclusion

The Loden group was faced with designing a readout system for its RPC chambers. While designing the system, the problem of cost and signal transmission were addressed and resolved. After a period of two months, a cheap but effective readout system was packaged. The readout package, which was designed, is currently being used to collect data.

References

1) Leo, William. " Techniques for Nuclear and Particle Physics Experiments" Berlin Germany: Springer-Verlag 1987.
2) Verkindit Didier. "The Neutrino: What is it?" wwwlapp.in2p3.fr/neutrinos/ankes.html Jun 16,2001

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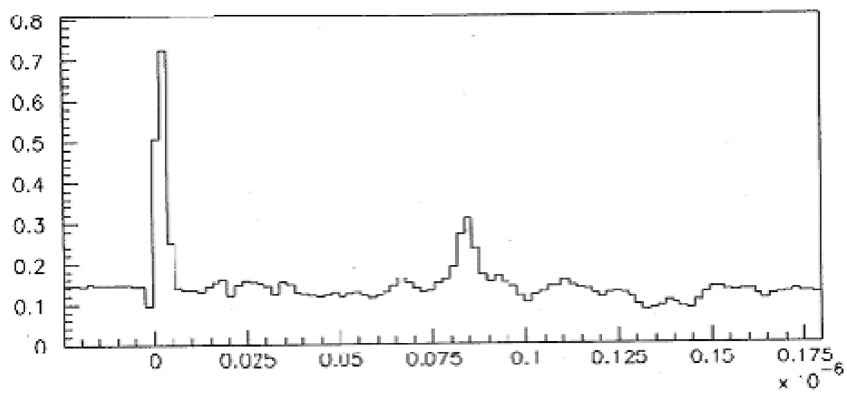
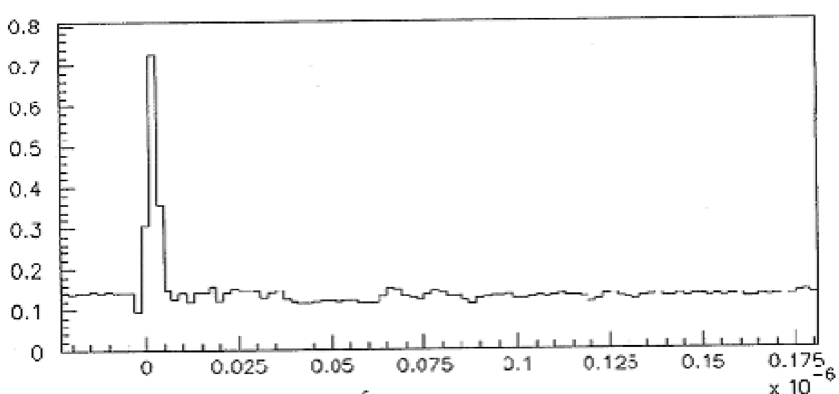
Appendix
PAW graphs of Oscilloscope Reading

strip width 1.3cm
terminating impedance 108.5ohms

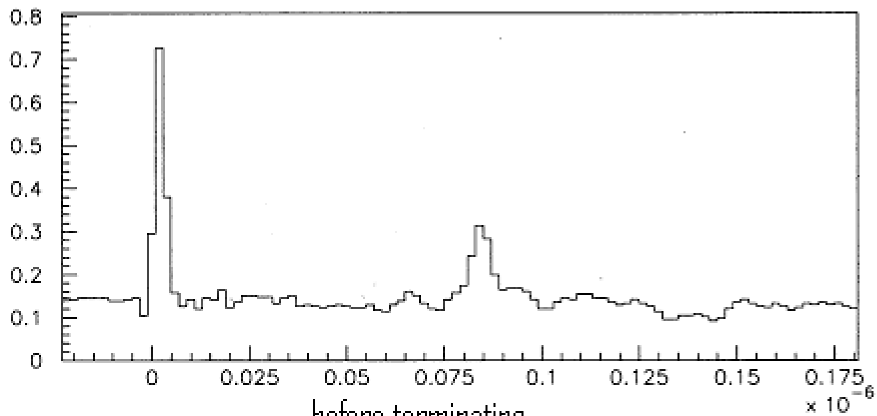


before terminating

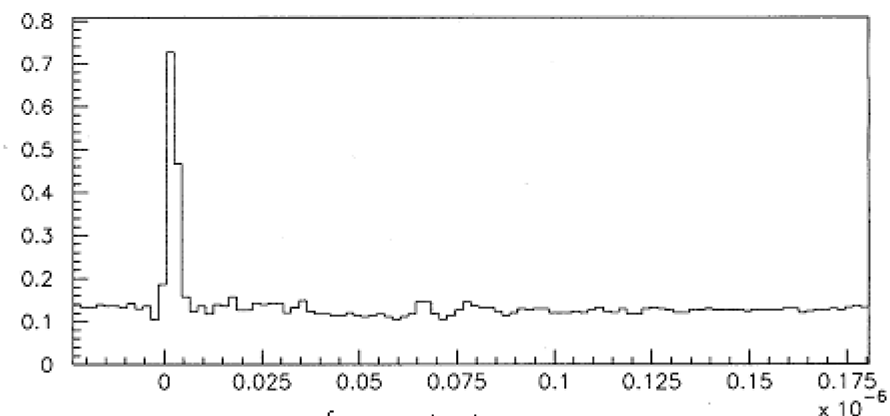


after terminating

strip width 1.8cm
terminating impedance 107.5ohms

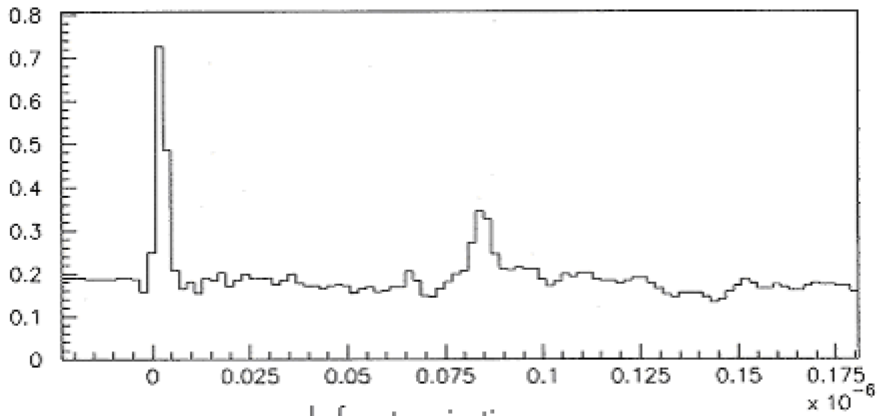


before terminating

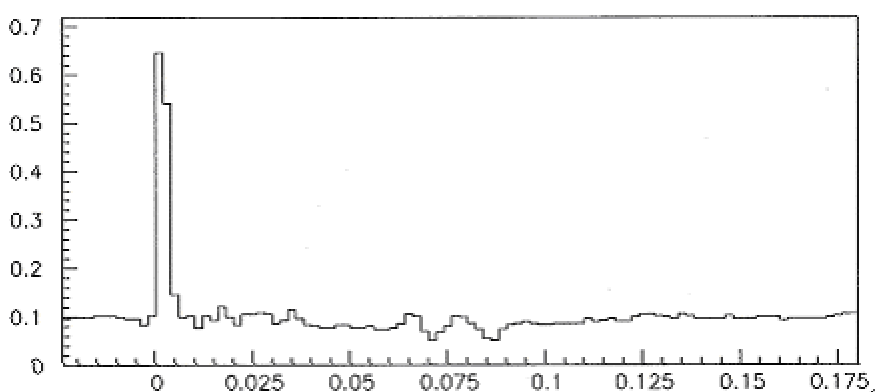


after terminating

strip width 3cm
terminating impedance 61.6 ohms



before terminating



after terminating